Decoupling of a Multi Channel Transmit/Receive Coil Array via Impedance Inversion

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Introduction: Using several channels in receive coils increases the Signal to Noise Ratio (SNR) [1]. Multi-channel transmit coils are used e.g. for RF-shimming. Techniques such as SensE [2] have been developed for reducing acquisition time. TSensE has been introduced to perform a similar function [3] during the transmit phase. For these applications, sufficient decoupling of the individual coil elements is essential. It improves the SNR in receive coils by reducing the noise coupling and increases the power efficiency for transmit coils. Coil coupling is mainly caused by mutual inductivities of the coil elements. To keep the coupling low, the ratio of mutual inductivity compared to self-inductivity can be reduced [4]. Coil elements, which are close to each other, can be decoupled using transformers or special coil geometries, so that the total mutual inductivity vanishes (e.g. [5,6,7]). This inductive decoupling is only useful for the decoupling of neighboring elements. The commonly used capacitive decoupling (e.g. used in [8]) is not an alternative, because it also cannot decouple each pair of elements by using a practicable network. Another drawback is the iterative adjustment procedure due to the interdependencies of the decoupling elements. The proposed method uses capacitors for decoupling, but each coupling among a pair of coil elements can be compensated independently by tuning one single capacitor. It uses quarter wave transmission lines between the coil ports and the decoupling network. It also enables a fairly easy implementation of the impedance matching and detuning of the coil.

Theory: The coupling of coil elements can be described by off-diagonal elements of an impedance matrix $\boldsymbol{Z}_\mathrm{c}$, related to the feeding ports of the unmatched coil. Usually, mutual inductivities $\jmath\omega M_{n_1,n_2}$ dominate the coupling: A current in one coil element induces a voltage in other coil elements. The decoupling can be achieved by connecting a second device $\boldsymbol{Z}_\mathrm{d}$ port-wise in series to the coil. The resulting impedance matrix is given by $\boldsymbol{Z}_\mathrm{c} + \boldsymbol{Z}_\mathrm{d}$. The proposed method uses impedance inversion of a capacitive network to synthesize a decoupling device $\boldsymbol{Z}_\mathrm{d}$.

An admittance Y is transformed to an impedance $Z = Z_0^2 Y$ by a quarter wave transmission line of the characteristic impedance Z_0. This relation can be generalized for a linear N-port device described by an admittance matrix $\boldsymbol{Y}$, which is connected to N quarter wave lines, with characteristic impedances given by the elements of a vector $\vec{\boldsymbol{Z}}_0$. In this case, the transformation is given by $\boldsymbol{Z} = \operatorname{diag}\vec{\boldsymbol{Z}}_0\,\boldsymbol{Y}\operatorname{diag}\vec{\boldsymbol{Z}}_0$. $\vec{\boldsymbol{Z}}_0$ can be chosen to match the input impedances of the coil-elements to the feeding cable impedances (e.g. 50Ω). However, losses of the quarter wave impedance lines generate additional loss resistances in the coil elements, which can be kept small by choosing low characteristic impedances. For decoupling, a matrix $\boldsymbol{Y}$ is used, which fulfills

$$\boldsymbol{Y} = \operatorname{diag}\vec{\boldsymbol{Z}}_0^{-1}\underbrace{\boldsymbol{Z}_\mathrm{d}}_{-\boldsymbol{Z}_\mathrm{c}}\operatorname{diag}\vec{\boldsymbol{Z}}_0^{-1}$$

at least at the non-diagonal elements. The diagonal elements only change the resonance frequency, which can be retuned by changing capacitors at other positions in the coil elements. Fortunately, it is quite easy to synthesize this admittance matrix with the demanded, individually tunable non-diagonal elements Y_{n_1,n_2}. This can be achieved by using a shared ground plane and lumped elements, $-Y_{n_1,n_2}$, between each two ports, n_1, n_2. In case of (positive) mutual couplings, these lumped elements are given by capacitors. A short to ground in this network is transformed into an open-circuit in the corresponding coil element by the quarter wave transmission line. This can be used for detuning.

Methods: An eight channel T/R-TEM-headcoil, decoupled via impedance inversion, was modelled using methods of [9,10] for a 3T System, built up and tested (Fig. 3). The elements of the coil were matched for a phantom load using two 10Ω semi-rigid cables (141C-10 MICRO-COAX) in parallel, resulting in a characteristic impedance of 5Ω. Decoupling was achieved via the proposed impedance inversion method. Images were acquired with each element, using an eight channel transmit 3T Philips Achieva System [11] to demonstrate the feasibility of the decoupling method.

Results: The scattering parameters in Fig.1 show the mode distribution of the matched, but coupled TEM resonator. Fig.2 shows the scattering parameters of the decoupled coil. Decoupling was realized for the next two neighbouring elements by impedance inverted capacitors, resulting in a maximum residual coupling of 14dB. Fig. 3 shows the results of the imaging experiment (T_1TFE; T_R=8ms, T_E=2.3ms). The intensity patterns of the individual coil elements confirm the efficiency of the decoupling method.

Conclusion: A new method for coil decoupling is presented, which is able to compensate for each coupling individually. It was implemented in a head coil, and imaging results were shown using an eight channel Transmit system. The method enables more complicated coil designs with a high number of channels and arbitrary coil shapes.

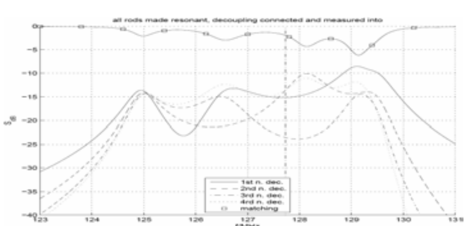

Figure 1: Simulated coupling of the coil without the decoupling capacitors

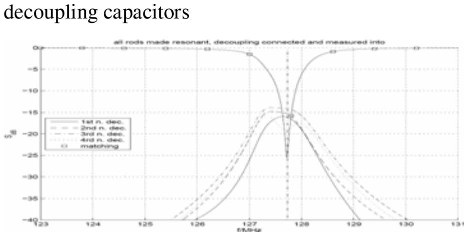

Figure 2: Simulated decoupling of the coil with decoupling capacitors (next two neighbors are decoupled)

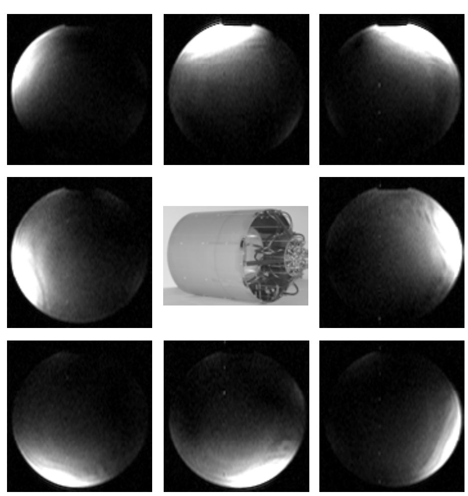

Figure 3:Individual images of the coil decopled by impedance inversion – The Images were generated on an Eight Channel Transmit Philips System at 3T.

References:
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